Relevance of the work. The dissertation is devoted to solving the scientific and applied problem of improving the technical means and technology of energy-saving, complex processing of waste slags of non-ferrous metallurgy and the inorganic part from the burning of Ekibastuz coal.

According to the Ministry of Industry and new technologies of the Republic of Kazakhstan, about 20 billion tons of solid waste have been accumulated in the dumps of mining and metallurgical enterprises. Of these, 10.1 billion tons are ferrous metallurgy waste, and 8.9 are non-ferrous metallurgy waste. The content of valuable components in waste often exceeds their concentration in the hard-to-enrich ores of "poor" natural deposits. Approximately 700 million tons of man-made waste is generated annually.

Another waste-forming fossil with a billion tons of reserves is Ekibastuz coal, which is characterized by high ash content (40-45%). The annual output of ash and slag from thermal power plants (TPP) when it is burned is an average of 30 million tons, with emissions of up to 200 grams of precious gallium and germanium per ton of coal. To date, more than 300 million tons of ash and slag waste have been accumulated in the ash dumps of the TPP. Utilization of waste metallurgical slag and ash and slag waste from thermal power plants, in order to extract useful components from them, is very important for the state from the point of view of solving the environmental problem.

However, in the field of processing man-made waste, there is still no technical solution that allows them to be processed cost-effectively. When developing metals from man-made waste, the specific consumption of primary fuel (respectively, CO2 emissions) increases by ~3 times, compared to their production from natural raw materials. If we also take into account that the projected term of depletion of reserves of rich mineral raw materials of the Republic of Kazakhstan is 30-35 years, then in the near future it may be necessary to process difficult-to-enrich, low-content valuable components of ores. In this regard, the development and creation of energy-saving melting equipment, waste-free technology for processing mineral raw materials, which together significantly reduce the specific fuel consumption (respectively, CO2 emissions) and thus meet modern technological challenges is urgent and urgent.

The purpose of this work is to develop energy-saving and environmentally perfect ways of processing metallurgical slag and ash waste from thermal power plants, thermal engineering bases and technical means for creating high-performance and continuously operating melting and recovery equipment that implements this process.

The research methods included the main provisions of the methodology of an integrated approach in the energy sector of heat technology, in order to implement intensive energy saving in the processing of man-made waste.
Computational and theoretical research was carried out with the development of mathematical models, algorithms and programs using computer technology. Laboratory studies on the "cold" model of the pilot plant were performed using methods of the theory of experiment planning. The transfer of the characteristics of the "cold" model to the "fire" pilot plant was carried out on the basis of the similarity theory and physical modeling. Recalculation of thermal and geometric parameters of the pilot plant for its projected industrial design was performed using the affine modeling method.

Metrological support for research. The devices and materials used in the research meet the requirements of the relevant regulatory and technical documentation. Research and chemical-analytical tests were carried out on the basis of certification methods, standards of the Republic of Kazakhstan and GOST operating on the territory of Kazakhstan.

**The scientific novelty of the work** consists of:
- development of a thermodynamically ideal scheme for processing metallurgical and energy waste, in which fuel and material costs are minimal;
- perform a comparison of energy consumption and materials corresponding to the ideal scheme, the scheme used and the proposed technology;
- development of technology for extracting Zn, Pb, Cu, Fe, Ga, Ge for processing metallurgical slags and ash waste from thermal power plants with reduced energy and material consumption;
- development of technology for producing water gas in the interaction of Ekibastuz coal and water vapor with the melt of metallurgical slag.

**Provisions for protection:**
- development of a thermodynamically ideal scheme for processing metallurgical slags and ash waste, which ensures minimal energy and material consumption;
- development of technology using a phase inversion reactor that allows extracting Zn, Pb, copper cast iron and rare elements (Ga, Ge) from poor ores and metallurgical slags with reduced fuel consumption;
- development of a scheme for utilization of the melting heat and the physical heat of the melt of metallurgical slags with the production of water gas;
- development of a mathematical model and development of a scheme for calculating fuel consumption in the processing of metallurgical slags and coal ash.

**Publications.** The main results of the dissertation are presented in 51 publications, including 27 international conferences, 3 journals indexed by Thomson Reuters, 8 journals recommended by the Committee for control in the field of education and science, 11 patents, and 3 other periodicals. The number of publications in English is 5.

**Approbation of the work:** The Main provisions of the dissertation were reported and discussed in International conferences, as well as in AUUES:


3 Dikhanbayev A., Ybray S. Principles of development and optimization of energy-saving technologies for high-ash coal gasification // Materials of the scientific and theoretical conference "Seifullin readings-12: Youth in science-innovative potential of the future" volume 1, part 3. – Astana. - 2016. - P. 146


The dissertation consists of an introduction, four chapters, and a conclusion. It contains 164 pages of the main text, 40 drawings, 30 tables, 5 appendices on 36 pages and a bibliography of 126 titles.

The first Chapter is devoted to the state of the issue, the formulation of research problems and the method of their solution. Thus, in order to assess the actual state of energy and resource saving in the field of processing of metallurgical slags, an analysis of fuel and material consumption in existing systems for fusing liquid and melting solid "rich" slags of mine smelting was carried out. Since ash slags are not processed in the Republic of Kazakhstan, Table 1 shows comparative thermal performance indicators only for installations that process solid slags (Welz-installation) and liquid slugs (slag-Loading installation).

Table 1 - Thermal characteristics of installations

<table>
<thead>
<tr>
<th>№</th>
<th>Specifications</th>
<th>Designation</th>
<th>Unit</th>
<th>Welz-installation</th>
<th>Slag-wasgonna installation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fuel efficiency</td>
<td>$\eta_{\text{Tоп}}$</td>
<td>%</td>
<td>52</td>
<td>55</td>
</tr>
<tr>
<td>2</td>
<td>Thermal efficiency</td>
<td>$\eta_{\text{Тепл}}$</td>
<td>%</td>
<td>30</td>
<td>46</td>
</tr>
<tr>
<td>3</td>
<td>The total index of waste products</td>
<td>$\psi$</td>
<td>%</td>
<td>15</td>
<td>19</td>
</tr>
<tr>
<td>4</td>
<td>Coefficient of use of thermal waste</td>
<td>$\eta_{\text{Исп}}$</td>
<td>%</td>
<td>10</td>
<td>14</td>
</tr>
</tbody>
</table>

From the consideration of Table 1, it can be concluded that the existing processes for processing "rich" slags have low technological and energy efficiency, and when processing "poor" slags, these indicators may be even lower.

The dissertation presents the proposed schemes for energy-saving and waste-free processing of "poor" metallurgical slags and ash slags of thermal power plants.

Chapter two deals with the task of creating systems for low-waste, environmentally friendly and cost-effective processing of mineral raw materials (coal, TPP ash, slag melts, fusing slag, clinker welts, etc.).

The standard of thermal technological perfection of the developed systems for waste-free and environmentally friendly processing of mineral raw materials is the value of the theoretically minimum specific fuel consumption in a thermodynamically ideal installation (TIU). By definition, TIU developed system is characterized by adiabatic walls fences working space of the furnace and heat utilizing elements countercurrent of flow (material, product of fuel combustion, air), infinitely high intensity of heat and mass transfer between the reactants, leading to immediate and complete end of physical and chemical processes, unlimited possibilities in the implementation of deep regenerative teplosbytovaya for infinitely small compatible energy.
The main task of high-temperature technology is to approximate the value of specific fuel consumption in the developed systems to its reference value.

The initial stage of the search is the choice of the object of study - DS; determination of types and amount of raw materials and energy, material, waste, energy losses and harmful emissions into the atmosphere at the DS; the Next stage of the search is the selection of low-waste technology for the proposed system (PS), development of energy-saving thermal schemes and the selection of high-performance melting equipment implementing the technology.

In order to determine the theoretically minimum fuel consumption and the potential of the energy saving reserve in the DS relative to the TIU, methods for calculating the fuel consumption for the DS processing of liquid, dump metallurgical slags and ash slags of TPP were developed. The calculation results are shown in table 2.

Table 2 - Summary characteristics of the compared systems

<table>
<thead>
<tr>
<th>№</th>
<th>Name characteristics'</th>
<th>Designation</th>
<th>Unit</th>
<th>System processing of «poor» moldboard slags'</th>
<th>System for processing &quot;rich&quot; liquid slags</th>
<th>Ash and slag recycling system for Heat and Power Stations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Specific reduced primary fuel consumption in a TIS</td>
<td>$\theta_{пр}^{ТИС}$</td>
<td>кг у.т. / т Zn</td>
<td>778</td>
<td>336</td>
<td>980</td>
</tr>
<tr>
<td>2</td>
<td>Specific reduced primary fuel consumption in the CS</td>
<td>$\theta_{пр}^{ДС}$</td>
<td>кг у.т. / т Zn</td>
<td>6000</td>
<td>3000</td>
<td>There is no current system</td>
</tr>
<tr>
<td>3</td>
<td>The efficiency of primary fuel in the CS relative to the TIS</td>
<td>$\eta_{\text{TU}}^\text{DC} \ %$</td>
<td>13.0</td>
<td>7.8</td>
<td>There is no current system</td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Potential of the energy saving reserve in the CS relative to the TIS</td>
<td>$\Delta \psi_{\text{pot}}^\text{DC} \ \text{kg} \ \text{u.t.} / \ \text{t} \ \text{Zn}$</td>
<td>5222</td>
<td>3953</td>
<td>There is no current system</td>
<td></td>
</tr>
</tbody>
</table>

Thus, as a result of calculating fuel consumption in operating (DS) and thermodynamically ideal systems (TIS) for processing slags and ash:
- the values of specific reduced primary fuel consumption in a thermodynamically ideal installation (TIU);
- the efficiency coefficients of operating systems relative to a thermodynamically ideal installation are determined;
- energy saving potentials in existing slag processing systems are calculated relative to a thermodynamically ideal installation.

**The third Chapter** presents the results of the development of theoretical and technical bases for building energy-and resource-saving systems for processing metallurgical slags and ashes of thermal power plants and testing the main element of this system – "phase inversion reactor-rotating furnace".

Based on the results of calculated and experimental studies, a pilot slag processing plant was designed and created at the production base of Otrar LLP. The plant consists of the following units: a fluidized melt bed reactor (RKSR) with a caissoned, water-cooled surface of 10m²; THE rksr has a garnissage lining from the inside; a rotating furnace 4m long, a fixed tubular furnace 4.5 m long and an air heater (VZP) with a heating surface of 200m² are lined with fireclay bricks; a draft blowing system including two air blowers V=80m³/min, P=1.8 ATM, W=200kW, each, two smoke pumps, W=45kW, each, an ejector scrubber of the SEJ type for a gas capacity of 5000nm³/h.; a chemical water treatment unit, a gas control unit and a transformer substation for 830 kVA; two slag bins with a capacity of 15 tons, each; a pool for melt granulation, with a mechanism for for slag removal; water supply system with two cooling towers; process oxygen line, 200m, extended from "oxygen"LLP. Figure 2 shows a schematic diagram of a pilot plant for processing slag.
1 – reactor of a boiling layer of the melt with the drum-separator, 2 – rotating part of the furnace 3 to the fixed part of the furnace with the heat exchange tubes of steel 12XH9T for pyrolysis of natural gas, 4 - air heater from the pipes 12XMΦ, 5 - steam superheater tubes of 15KHM, 6 – intake manifold additional natural gas, 7 – laksarska pipe, 8 – drive tubular furnace, 9 - seal gaps of a rotating part of the furnace. 10-ejector scrubber, 11-furnace, PRG-natural gas, SHS-carbon black mixture, GG-combustible gas, W-slag, P-melt.

At the pilot plant based on the "phase inversion reactor - rotating furnace" unit, experiments were conducted to recover iron from lead smelting slags. Product range: zinc in vozgonah-90 kg / h, carbon-containing iron-copper alloy (copper cast iron) - 200 kg / h, silicate melt suitable for stone-making-600-700 kg/h, combustible gas with a lower heat of combustion 7100-7200 kJ / m$^3$ and heat capacity of 1600-1700$^0$S.

Final slag composition, in%: 1.66 Zn, 0.15 Pb, 0.17 Cu, 7.5 FeO, 41SiO$_2$, 27.8 CaO, 12, 5Al$_2$O$_3$, 8.5 MgO, 30-40 g / t Ge. This composition of the melt makes it possible to obtain slag grade 75 or stone products.

Based on the experimental data, in the Appendix of the thesis, recalculated the thermal performance of the pilot plant capacity 1.5 t/h slag at the industrial design unit "reactor phase inversion-rotary kiln" (RIF-VP), performance slag 31 t/h. According to calculations, given the specific fuel consumption in REEF – trip in ~ 4 times less than in current industrial'ts-furnace processing slag of identical composition.

Thus, experimental studies have confirmed not only the efficiency, but also the great potential of the unit "phase inversion reactor-rotating furnace" for continuous, energy-saving processing of slags and other man-made waste. The results of the test at the pilot plant allowed us to obtain the necessary experimental data for the development and creation of a highly efficient industrial plant for continuous processing of mineral raw materials.

The fourth Chapter is devoted to the development of energy-saving thermal schemes for a practical model of the system for joint processing of
metallurgical slags and ash from thermal power plants. The forecast of obtaining water gas with an additional mole of hydrogen during joint steam purging of iron-containing metallurgical slags, HPS ash and Ekibastuz coal in a gasifier is given.

Figure 3 - Technological scheme of joint processing of metallurgical slags and ashes of the Heat and Power Station

1-phase inversion reactor, 2-rotating furnace, 3-water gas production unit, 4-dust chamber, 5-high-temperature air heater, 6-scrubber, e-ejector, VG-water gas, V-blowing air, EU-Ekibastuz coal, CSH-zinc slag, I-limestone, W-slag, P-dust.

The developed energy-saving thermal scheme for waste-free processing of slags and ashes has the following advantages over its existing analogues.

- The calculated heat of combustion of hydrogen-rich fuel gas (11586 kJ/m³) is greater than that of steam-air (4200-4600 kJ/m³) and steam-oxygen blast (8800-9200 kJ/m³) and is close to its theoretical limit (11700 kJ/m³).
- The unit "phase inversion reactor-rotating furnace-gas generator" eliminates the following disadvantages of a traditional gas generator-burning of part of the coal with steam-air or steam-oxygen blowing, heat loss when drying wet coal and loss of part of the coal with ash-slag waste of the process.
- Joint gasification of Ekibastuz coal and metallurgical slags will allow obtaining hydrogen-enriched combustible gas that can be used for the production of technical hydrogen.
- Simultaneous production of several products (copper cast iron, zinc, gallium and germanium distillates, combustible gas, slag / stone casting) will reduce the cost of combustible gas compared to gas produced in a traditional gas generator.
The thesis presents a comparative heat engineering calculation and evaluation of the economic efficiency of the RIF-VP-GG unit relative to the operating system and thermodynamically ideal installation (see table.3).

Table 3 - Summary of heat engineering and economic characteristics of the compared systems

<table>
<thead>
<tr>
<th>Name of characteristics</th>
<th>Designation</th>
<th>Unit</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific reduced primary fuel consumption in TIS of slag processing</td>
<td>$V_{Пр}^{ТИС}$</td>
<td>кг у.т. / т Zn</td>
<td>778</td>
</tr>
<tr>
<td>Specific reduced primary fuel consumption in the current slag welling system</td>
<td>$V_{Пр}^{ДС}$</td>
<td>кг у.т. / т Zn</td>
<td>6000</td>
</tr>
<tr>
<td>Specific reduced primary fuel consumption in the proposed slag processing scheme</td>
<td>$V_{Пр}^{ПС}$</td>
<td>кг у.т. / т Zn</td>
<td>1136</td>
</tr>
<tr>
<td>The efficiency of primary fuel in the CS of slag welling in relation to the TIS</td>
<td>$\eta_{ДС}^{ТИС}$</td>
<td>%</td>
<td>13,0</td>
</tr>
<tr>
<td>The potential of the energy saving reserve in the CS of slagging relative to the TIS</td>
<td>$\Delta V_{Пр}^{ДС}$</td>
<td>кг у.т. / т Zn</td>
<td>5222</td>
</tr>
<tr>
<td>Potential of the energy saving reserve in the developed slag processing system relative to the CS</td>
<td>$\Delta V_{Пр}^{ПС}$</td>
<td>кг у.т. / т Zn</td>
<td>4864</td>
</tr>
<tr>
<td>Specific economic effect of the proposed system implementation</td>
<td>$\mathcal{E}_{ПС}$</td>
<td>тенге / т Zn</td>
<td>36175</td>
</tr>
<tr>
<td>Payback period for capital investments</td>
<td>$\tau$</td>
<td>years</td>
<td>2,5</td>
</tr>
</tbody>
</table>

This situation encourages the search for new methods and technical solutions that further improve the energy efficiency of the system for processing slag from "poor" factory dumps.

Recommendations for industrial use of the results of the dissertation work

The following enterprises of the Republic of Kazakhstan can be recommended as areas of application of the unit "phase inversion reactor-rotating furnace-gas generator":

- Thermal power plants (ash), Leninogorsk polynmetallic plant (clinker weltsevaniya), JSC "Kazzinc" (zinc-poor slags), the former plant "achpolimetall" (clinker weltsevaniya), PC "Yuzhpolimetall" (zinc-poor slags), Balkhash zinc and Dzhezkazgan copper smelters (copper smelting slags), Karaganda metallurgical plant (ArcelorMittal), (zinc-containing dust and blast furnace slag), owner of the Syrymbet tin ore (tin concentrates), owner of the Shalkiya lead ore (Lead concentrates), Novo-Dzhambul Phosphorous Plant (phosphate-a trifile-waste).

In non-ferrous metallurgy enterprises, zinc, germanium and gallium distillates (ZnO, Ga2O3, GeO2) are processed into metallic zinc, germanium,
gallium, gallium arsenide or nitride, or into their other compounds, the demand for which is growing in the world.

The main consumers of copper cast iron is the Karaganda steel mill (ArcelorMittal), and combustible gas - in Central and Northern regions of Kazakhstan. Potential consumers of slag and stone paving and curbstone slabs are construction companies of housing and communal services of the Republic of Kazakhstan.

**Main results and conclusions.**

- It is shown that the low energy, technological and environmental efficiency of slag processing by traditional technology and smelting equipment is due to the imperfection of the structure of the thermal scheme.
  – It is recommended that for energy-saving, environmentally acceptable and cost-effective recovery of iron from slag (with its conversion to cast iron), it is necessary to develop a technology for obtaining gas fuel enriched with hydrogen. Ekibastuzky coal can serve as a cheap source for this technology.
- Thermal schemes of thermodynamically ideal installations for processing metallurgical slags and TPP ash waste have been developed, and a calculation method has been developed for determining the values of the theoretically minimum fuel consumption in a thermodynamically ideal installation.
  – a model for searching for energy-saving systems for low-waste processing of raw materials has been created.